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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF THE FLOW IN AN ANNULAR-DIFFUSER—TAILPIPE COMBINATION WITH AN ABRUPT AREA EXPANSION AND SUCTION, INJECTION, AND VORTEX-GENERATOR FLOW CONTROLS

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PRELIMINARY INVESTIGATION OF THE FLOW IN AN ANNULAR-DIFFUSER—TAILPIPE COMBINATION WITH AN ABRUPT AREA EXPANSION AND SUCTION, INJECTION, AND VORTEX-GENERATOR FLOW CONTROLS

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SUMMARY

The performance of an annular-diffuser—tailpipe combination with an abrupt area expansion was investigated with and without flow controls in the form of suction, injection, and vortex generators. The diffuser had a 21-inch-diameter straight outer wall, an area ratio of 1.9 to 1, and fully developed pipe flow at the inlet. Inlet Mach number was varied between 0.18 and 0.43 with a resulting maximum Reynolds number (based on inlet hydraulic diameter) of approximately 1.6×10^6. The ratio of the auxiliary air flow to the flow of the main stream was varied from 0 to approximately 4 percent.

Rounding the sharp edge of the terminus of the center body to a radius of $1\frac{1}{2}$ inches eliminated a vena contracta which occurred with the sharp-edged dump, and resulted in a 200-percent increase in the static-pressure rise across the first diameter of length of tailpipe. Both suction and injection flow controls were effective in producing improved diffuser performance. Further research is needed to reduce the amount of auxiliary flow required for satisfactory diffuser performance and to reduce the pumping losses in the auxiliary flow.

INTRODUCTION

The performance characteristics of subsonic-annular-diffuser designs applicable to turbojet afterburners are being studied in a research program initiated to develop short configurations which provide stable flow, reasonably uniform diffuser-exit velocity distributions, and efficient performance, all of which are important for satisfactory afterburner performance.

[redacted]

The first reports of this program are references 1 to 4. References 1 and 2 establish performance values with and without vortex-generator controls for a typical annular diffuser with conical afterbody. The overall length of the diffuser was such as to correspond to an equivalent cone angle of 15°. The effect of terminating the center body abruptly and sharply, thus producing an abrupt area expansion, is described in reference 3. The two investigations, the 15° and the abrupt dump diffusers, have served to establish reference points in the development of short, efficient annular diffusers. The 15° diffuser with vortex-generator control provided as efficient a performance as can be expected in practice; whereas the abrupt dump represents the other extreme, a diffuser with all the area expansion taken at one station and with a correspondingly inefficient performance. The relative merit of other diffuser designs may be determined through performance comparisons with these two reference diffusers. The investigation reported in reference 4 indicated that a performance comparing favorably with the 15° diffuser could be obtained with a shorter diffuser of 24° equivalent cone angle and with vortex-generator control.

The investigation of the abrupt dump diffuser indicated that the diffusion per unit length in the constant-area tailpipe was severely penalized by the formation of an extensive vena contracta region downstream from the abruptly terminated center body. Downstream from the vena contracta region, the diffusion proceeded at a rate comparable to that of the 15° diffuser. These results suggested that an efficient short diffuser design might be obtained by rounding the sharp edge of the abruptly terminated center body in order to eliminate the vena contracta region and start the diffusion process. Through the use of flow controls, it was anticipated that attached flow could be maintained on a surface of fairly small radius. Such a diffuser design has been investigated, and the results are reported herein.

The performance of the modified dump design was determined with no controls and with suction, injection, and vortex-generator controls. The inlet conditions corresponded to fully developed pipe flow, mean Mach numbers ranging from 0.18 to 0.43, and resulting maximum Reynolds number (based on hydraulic diameter) of approximately 1.6×10^6.

SYMBOLS

D	diffuser outer diameter
H	total pressure
ΔH	total-pressure loss

l	longitudinal distance along tailpipe axis measured from end of center body
M	Mach number
n	exponent in velocity distribution law, $\frac{u}{U} = \left(\frac{y}{\delta}\right)^n$
p	static pressure
Δp	static-pressure rise
P	auxiliary air-pumping energy coefficient
q_c	impact pressure, $H - p$
r	radial distance from diffuser center line
R	ratio of auxiliary air-volume flow to main stream-volume flow at inlet station, percent
R_n	Reynolds number
u	local velocity
U	maximum velocity occurring in radial velocity distribution
y	perpendicular distance from wall
δ	boundary-layer thickness
δ^*	boundary-layer displacement thickness, $\int_0^\delta \left(1 - \frac{u}{U}\right)dy$
θ	boundary-layer momentum thickness, $\int_0^\delta \frac{u}{U}\left(1 - \frac{u}{U}\right)dy$
δ^*/θ	boundary-layer shape parameter
η	diffuser effectiveness

Subscripts:

1	diffuser inlet station
2, 3	downstream diffuser stations
X	variable downstream diffuser station
N	no auxiliary flow
R	variable auxiliary air-flow ratio
in	reference to diffuser inner wall
out	reference to diffuser outer wall
S	suction
I	injection

Bar over symbol indicates a weighted average quantity.

APPARATUS AND PROCEDURE

Test Equipment

A diagram of the experimental setup is shown in figure 1. Atmospheric air entered the cylindrical screen section and passed through an inlet bell, which was connected to the test diffuser by approximately 27 feet of annular ducting having an inner diameter of $14\frac{1}{2}$ inches and an outer diameter varying from 21 to 25 inches. Downstream ducting connected the setup to an exhauster. The center body of the annular approach duct was used as an auxiliary air duct and was connected to a blower or exhauster according to whether injection or suction flow control tests were in progress. The auxiliary air duct was fitted with a flow-measuring orifice designed and installed according to A.S.M.E. standards (ref. 5).

A detailed drawing of the modified dump and adjacent ducting is given in figure 2. All internal surfaces and joints were filled and sanded for several feet upstream from the diffuser inlet station. The plate covering the end of the center body was hardwood with the outer edge rounded to a $1\frac{1}{2}$-inch radius, as shown, and a groove 1/2 inch deep by 1/2 inch wide cut in the downstream face on a $10\frac{1}{2}$-inch-diameter center line. For the auxiliary flow tests, 40 equispaced 3/8-inch-diameter holes were drilled longitudinally through the hardwood plate at the base of the groove.

Instrumentation

Stream total and static pressures were measured by four equally spaced, remote-controlled survey rakes at the diffuser inlet station, station 1, and the tailpipe stations, stations 2 and 3. Flow surveys were made at only one station at a time so that there were no instruments in the stream ahead of the measuring station. Stagnation-temperature measurements were taken at a point in the approach annulus several diameters upstream from the diffuser inlet, and measurements of the stagnation pressure and temperature were taken in the auxiliary air duct about 1 inner-body diameter from the hardwood plate.

Static-pressure orifices extending from upstream of the diffuser inlet station to station 3 were installed along a single generatrix on the outer wall. At each of the three stations, four equispaced static orifices were located on the outer wall.

All pressure measurements were made with multitube manometers containing a fluid whose specific gravity was 1.75. The manometer scales were read to the nearest tenth of a centimeter.

Tests

Before drilling the 3/8-inch-diameter holes in the hardwood plate (see fig. 2), the performance of the modified dump diffuser was investigated over a range of inlet Mach number without flow controls. Total- and static-pressure surveys were made at stations 1 and 3 and wall static-pressure and reference readings were recorded. The same configuration was investigated with vortex-generator controls consisting of 24 NACA 0012 symmetrical rectangular airfoil sections with 3-inch chord and 1/2-inch span set counterrotating at $\pm 15^{\circ}$ with the longitudinal axis of the diffuser. The effectiveness of the vortex generators was determined for two vortex-generator locations, 1 inch and 6 inches upstream from the end of the center body.

After completing the aforementioned tests, the hardwood plate was drilled and the suction and injection control tests were run. The inlet Mach number was varied over a range from 0.18 to 0.43 in a limited number of cases to establish trends. Most of the downstream surveys were made at station 3 because total-pressure readings at this station were considered to be more accurate than at station 2 because of the more uniform velocity distributions.

Basis of Comparison

The description of the flow development and the effectiveness of each flow-control method in promoting diffusion is presented in terms of the longitudinal distributions of static-pressure coefficient $\frac{\Delta p_{1-x}}{q_{c_1}}$, the radial distribution of relative velocity $u/\bar{u}_1$, and the local change in total pressure with suction or injection control $\frac{(H_3)_R - (H_3)_N}{(\overline{\Delta H}_{1-3})_N}$. The overall performance in terms of the mean coefficients $\frac{\overline{\Delta p}_{1-2}}{\overline{q_{c_1}}}$, $\frac{\overline{\Delta H}_{1-2}}{\overline{q_{c_1}}}$, and $\frac{\overline{\Delta H}_{1-3}}{\overline{q_{c_1}}}$ is also given.

For purposes of evaluating the modified dump performance corrected for pumping energies required for the suction and injection control, the static-pressure-rise coefficient was converted to an effectiveness which is defined as the ratio of the measured static-pressure-rise coefficient to the input static-pressure coefficient $\frac{\overline{\Delta p}_{1-2}/\overline{q_{c_1}}}{\left(\frac{\Delta p}{\overline{q_{c_1}}}\right)_{input}}$ where the input static-pressure coefficient is the sum of the pumping energy coefficient and the theoretical, one-dimensional, isentropic static-pressure coefficient corresponding to the mean inlet static and total pressures and the diffuser area ratio. The pumping energy coefficients are defined in figure 3. In order to evaluate the pumping energy, it was necessary to assume a hypothetical source for the injection air and a hypothetical exit for the suction air. In both cases, the diffuser inlet was assumed as the reference station, thus confining the auxiliary air system to the diffuser proper and eliminating any variables which would be impossible to assess in applying the results. It was assumed that the auxiliary air-flow pump operated at an efficiency of 100 percent. In the case of injection, it was assumed that a pump would have to supply a pressure rise equal to the difference between the inlet static pressure and the measured total pressure in the chamber upstream from the injection holes. For suction, it was assumed that the pump would supply a pressure rise equal to the difference between the inlet mean total pressure and the chamber total pressure. The corrected total-pressure-loss coefficient was obtained simply by adding the pumping coefficients to the measured loss coefficients.

RESULTS AND DISCUSSION

Inlet Measurements

In order to define the inlet flow conditions, which are pertinent factors governing the flow development throughout any diffuser, inlet-total-pressure surveys were made at four equally spaced circumferential stations. Ultimately, these measurements were also used in determining overall diffuser performance coefficients. Boundary-layer profiles determined by using the survey data are presented in figure 4 in terms of the ratio of local velocity to the maximum velocity as a function of radial position in the annulus. Since no significant circumferential variations were measured, the average of the four sets of data is presented. In addition, figure 4 indicates negligible differences between the data for the inner and outer wall with respect to velocity profiles and the significant boundary-layer parameters listed. The boundary layer filled the entire annulus, similar to fully developed pipe flow, and the use of flow controls did not alter the inlet conditions for the range of variables tested. The diffuser performance presented herein is conservative in comparison with the systems sketched in figure 3, where either the injection-system inlet or suction-system outlet would serve as diffuser-inlet boundary-layer controls. The inlet boundary layer of the investigation reported herein is essentially the same as that of references 2 to 4.

Longitudinal Static-Pressure Distribution

A convenient index to the flow development for a given diffuser is the longitudinal static-pressure distribution, since the change in pressure per unit length is indicative of the rate of change of the mean dynamic pressure. Plots of the static-pressure-rise coefficient as determined from the outer-wall static-pressure orifices are given in figure 5 as a function of diffuser length for control and no control. The values given are slightly higher than mean values in the region immediately downstream from the center body because of radial pressure gradients such as those described in reference 3 and have not been corrected for injection and suction pumping powers.

No-control values over a range of inlet Mach number are compared in figure 5(a) with those obtained in the investigation of the sharp-edged dump of reference 3 and of the 15° diffuser of reference 2. A small, unfavorable effect due to increasing speed is apparent. The comparison of the data for the rounded and sharp-edged dumps indicates that the $1\frac{1}{2}$-inch radius on the center-body terminus was responsible for the elimination of the vena contracta obtained with the sharp-edged dump and described in reference 3. This effect resulted in an increase in the static-pressure-rise coefficient at the station with $l/D = 1.0$ of about 200 percent. The comparison of the data for the rounded dump with the 15° diffuser indicates that the rounded dump produced only 69 percent of the 15° diffuser static-pressure rise at the station with $l/D = 1.0$. These data comparisons indicate that radii larger than $1\frac{1}{2}$ inches would probably produce further improvements in the performance, since the longitudinal static-pressure distribution for the rounded dump contains a region of appreciable length where there is no static-pressure rise.

The effect of withdrawing air through the holes drilled in the end of the center body (see fig. 2) by applying suction to the center duct is shown in figure 5(b). Increasing suction rates tended to remove the reverse curvature in the longitudinal static-pressure distribution in the region just downstream from the center body and resulted in an increase in the static-pressure coefficient at the 1-diameter station of 40 percent over that for no control. Presumably, the increased performance was a result of removing air from the turbulent back-flow region just downstream from the center-body terminus, thus permitting the main stream to diffuse more rapidly.

The effect of injecting high-energy air through the same holes used for suction control is presented in figure 5(c). The purpose of injection control was to confine radially the turbulent back-flow region just downstream from the center body, thus permitting more rapid diffusion of the inlet flow. Figure 5(c) indicates that the injection flow control was also successful. The highest injection rates eliminated completely the reverse curvature in the longitudinal static-pressure distribution in the region just downstream from the end of the center body. This effect produced an increase in the actual static-pressure-rise coefficient at the 1-diameter station of about 43 percent. A part of the increased static pressure for the injection runs must also be attributed to the higher mean total pressure of the flow resulting from injection, exclusive of any flow-control effects. The curves of figure 5(c) also indicate that injection improved the diffusion in the region of the rounded surface probably by an injector action which induced the main flow to follow the rounded surface. Both the suction and injection controls produced static pressures at the 1-diameter station comparable to those of the 15° diffuser with no control.

The effectiveness of vortex-generator control in promoting better mixing was investigated briefly and the results are presented in figure 5(d). It was found necessary to move the vortex generators 6 inches upstream to obtain appreciable performance gains, which effectively lengthened the diffuser undesirably. A gain in static pressure at the 1-diameter station of 32 percent over that for no control is indicated for the upstream vortex-generator location.

The data of figure 5 are sufficient for sketching rough approximations of the flow patterns in the diffuser for the various control systems. Such sketches, figure 6, are useful for illustrating the flow immediately downstream from the inner body and the apparent effects of injection and suction control on the back-flow region. A figure taken from reference 3, figure 6(a), has been included to illustrate by comparison with figure 6(b) the beneficial effect of the rounded surface on the vena contracta. The effect of injection on confining the back-flow region is apparent from comparing figures 6(b) and 6(c). Figure 6(d) indicates that suction controls the back-flow region by removing the low-energy air in this region.

Radial Distributions

Radial pressure surveys were made at the downstream stations in order to determine the effectiveness of control in producing more uniform total-pressure and velocity distributions. Figure 7 illustrates the effect of injection on the flow at stations 2 and 3 in terms of the ratio of local velocity to the mean inlet velocity as a function of an area term (the radius squared).

Data for the no-control cases were taken at station 3 only. The effect of injection on the velocity distribution at station 3 was minor, whereas injection produced some improvements in the distributions at station 2. From figure 5, it can be seen that the improved distributions due to injection probably extended over the first diameter of length. Figure 7 indicates considerable mixing between stations 2 and 3. Since the alinement and location of the injection jets were selected arbitrarily, it may be safely assumed that the design is not optimum. The effects of injection location and alinement should be investigated further for the purpose of obtaining more control over the flow and velocity distribution since the results of the present preliminary investigation indicate that injection is effective in producing increased static-pressure rise.

A comparison of velocity distributions obtained at station 3 with no control, injection, or suction is presented in figure 8. The suction data indicate a strong tendency towards moving the air to the center of the duct at the expense of the flow near the outer wall. This result indicates that for this diffuser configuration suction control is more effective than injection in producing uniform velocity distributions at station 3.

The effect of control on radial total-pressure distributions at station 3 is illustrated in figure 9, where the ratio of the difference between local total pressures with and without control to the total-pressure loss without control is presented as a function of radius squared. The function plotted is equivalent to the local improvement in total pressure due to control in terms of the no-control loss. The no-control case corresponds to zero values at all radii.

The effect of suction control was an increase in the total pressure near the center of the duct by control of the back-flow region and a decrease in the total pressure near the outer wall as a result of the boundary-layer development in a higher adverse gradient. These effects are reflected directly in the velocity distributions of figure 8.

The effect of injection control for the 2.06-percent case was unfavorable since higher losses were produced in the inner half of the duct indicating a detrimental effect on the back-flow region. The highest injection rates produced approximately constant additions of total pressure across the duct which were accompanied by higher static pressures producing little net effect on the velocity distributions of figure 8.

Mean Performance Coefficients

Static-pressure-rise coefficient.- The effect of suction and injection control on the actual static-pressure-rise coefficient at station 2 is illustrated in figure 10 as a function of mean inlet Mach number. Actual data points are plotted and faired curves corresponding to constant values of percentage suction or injection air have been drawn. The data indicate that increasing Mach number has a typically detrimental effect on static-pressure recovery. About 4-percent injection or suction flow produced approximately 40-percent increase in the actual static-pressure rise over that obtained with no control.

In order to illustrate the effect on static-pressure coefficient of varying the amount of suction or injection flow for several tailpipe lengths, a cross plot of figures 5 and 10 is presented in figure 11. Static-pressure-rise coefficient at an inlet Mach number of about 0.26 is given as a function of percent auxiliary air flow for curves of constant tailpipe length. The curves show conclusively that suction control produces higher static-pressure coefficients up to about $3\frac{1}{2}$ percent auxiliary air flow for tailpipe lengths greater than about 0.6D. For tailpipe lengths of less than about 0.6D, injection is superior to suction because suction failed to control the flow over the rounded section. Suction produced improved performance at any auxiliary flow; whereas at tailpipe lengths of 1 diameter or more, up to 2-percent injection had no effect.

Total-pressure-loss coefficient.- Measured total-pressure-loss coefficients (not corrected for pumping power) between the inlet and stations 2 and 3 are presented in figure 12 as a function of inlet Mach number. Faired curves at constant values of percent auxiliary air flow are included. The reduction in loss coefficient with increasing percentage of suction air flow is indicative of the amount of low-energy air removed by the suction. The large drop in loss coefficient with increasing injection air flow, however, is largely due to the high energy of the injection air raising the mean energy of the stream exclusive of any flow-control effects. A comparison of the injection data for stations 2 and 3 indicates mixing and friction-loss coefficients in the tailpipe length from stations 2 to 3 of approximately 2 percent. The vortex-generator installation which was located 6 inches upstream from the end of the center body produced at an inlet Mach number of 0.26 a loss coefficient about 7 percent higher than that for no control.

Coefficients corrected for pumping power.- An accurate assessment of control performance which involves movement of auxiliary flows cannot be accomplished unless pumping powers are considered in the performance parameters. Pumping-power coefficients calculated for the purpose of correcting the measured static-pressure-rise and total-pressure-loss coefficients according to methods described in a previous section are presented in figure 13 as a function of percent of auxiliary flow. At a given percent auxiliary air flow, the pumping powers for suction were slightly greater than those for injection. The pumping powers increase rapidly with increased auxiliary flow and approach values equivalent to the no-control total-pressure-loss coefficient at values of R from $3\frac{1}{2}$ to 4 percent. The pump pressure rise required for a given value of R is readily calculable from the data of figure 13. Since no effort was expended in determining optimum areas for the auxiliary air holes, the pumping-power-coefficient values must be regarded as somewhat arbitrary.

The diffuser effectiveness including the pumping-power correction and based on the static-pressure-rise measurements to station 2 are presented in figure 14 as a function of percent auxiliary airflow. Total-pressure-loss coefficients at station 3 corrected for pumping power are also included.

For purposes of comparison, performance points for no control for the 15° diffuser of reference 2 and the sharp-edged dump of reference 3 have been indicated in figure 14. Comparison of these data with the subject-diffuser data indicates that with no control the modified dump produced about 80 percent of the loss coefficient of the sharp-edged dump, but exceeded the loss of the 15° diffuser by 170 percent. It is apparent from figures 5 and 14 that, although injection and suction controls were effective, the pumping powers required for the subject configuration were excessive and prevented the attainment of the performance of the 15° diffuser. These results suggest that means for reducing the required pumping powers should be investigated further. Pumping powers may be reduced both by determining more efficient auxiliary-air-system designs and by reducing the control requirements of the diffuser by accomplishing more of the diffusion in the conventional manner of increasing the cross-sectional area at moderate rates prior to dumping the flow.

CONCLUSIONS

The performance of an annular-diffuser—tailpipe combination with an abrupt area expansion was investigated with and without flow controls in the form of suction, injection, and vortex generators. The diffuser had a 21-inch-diameter straight outer wall, an area ratio of 1.9 to 1, and fully developed pipe flow at the inlet. Inlet Mach number was varied between 0.18 and 0.43 with a resulting maximum Reynolds number (based on inlet hydraulic diameter) of approximately 1.6×10^6. The ratio of the auxiliary air flow to the flow of the main stream was varied from 0 to approximately 4 percent. The following conclusions are presented:

1. Rounding the sharp edge of the terminus of the center body to a radius of $1\frac{1}{2}$ inches was responsible for the elimination of the vena contracta effect resulting in a 200-percent increase in the static-pressure rise across the first diameter of length of tailpipe as compared with that obtained with the sharp-edged dump.

2. At the same tailpipe station, the rounded dump produced 69 percent of the static-pressure rise of a 15° annular diffuser previously investigated. The longitudinal static-pressure distributions indicated that a larger radius at the center-body terminus probably would produce further gains in performance.

3. Suction and injection control produced 40- and 43-percent increases, respectively, in the measured static-pressure rise to the 1-diameter tailpipe station. A vortex-generator installation produced a 32-percent increase in the static-pressure rise to the same station; however, it was necessary to locate the generators an appreciable distance upstream from the diffuser which effectively lengthened the diffuser undesirably.

4. Radial pressure surveys at the tailpipe stations showed that the higher injection rates produced roughly uniform increases in the total pressure across the section; whereas suction control increased the total pressure and velocity near the tailpipe center line at the expense of the total pressure in the outer half of the duct.

5. The pumping powers required for suction and injection control for the configuration tested were excessive and reduced the measured performance gains of approximately 40 percent to gains corrected for pumping power of 13 and 6 percent for suction and injection, respectively. This result suggests that in order to reduce the pumping powers the basic diffuser design should be improved and more efficient auxiliary-air-system designs should be determined through further investigations.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 17, 1953.

REFERENCES

1. Wood, Charles C.: Preliminary Investigation of the Effects of Rectangular Vortex Generators on the Performance of a Short 1.9:1 Straight-Wall Annular Diffuser. NACA RM L51G09, 1951.

2. Wood, Charles C., and Higginbotham, James T.: The Influence of Vortex Generators on the Performance of a Short 1.9:1 Straight-Wall Annular Diffuser With a Whirling Inlet Flow. NACA RM L52L01a, 1953.

3. Wood, Charles C., and Higginbotham, James T.: Flow Diffusion in a Constant-Diameter Duct Downstream of an Abruptly Terminated Center Body. NACA RM L53D23, 1953.

4. Wood, Charles C., and Higginbotham, James T.: Performance Characteristics of a 24° Straight-Outer-Wall Annular-Diffuser—Tailpipe Combination Utilizing Rectangular Vortex Generators for Flow Control. NACA RM L53H17a, 1953.

5. Anon.: Flow Measurement by Means of Standardized Nozzles and Orifice Plates. Supplement on Instruments and Apparatus, pt. 5, ch. 4, Power Test Codes, A.S.M.E., 1949, pp. 5-62.

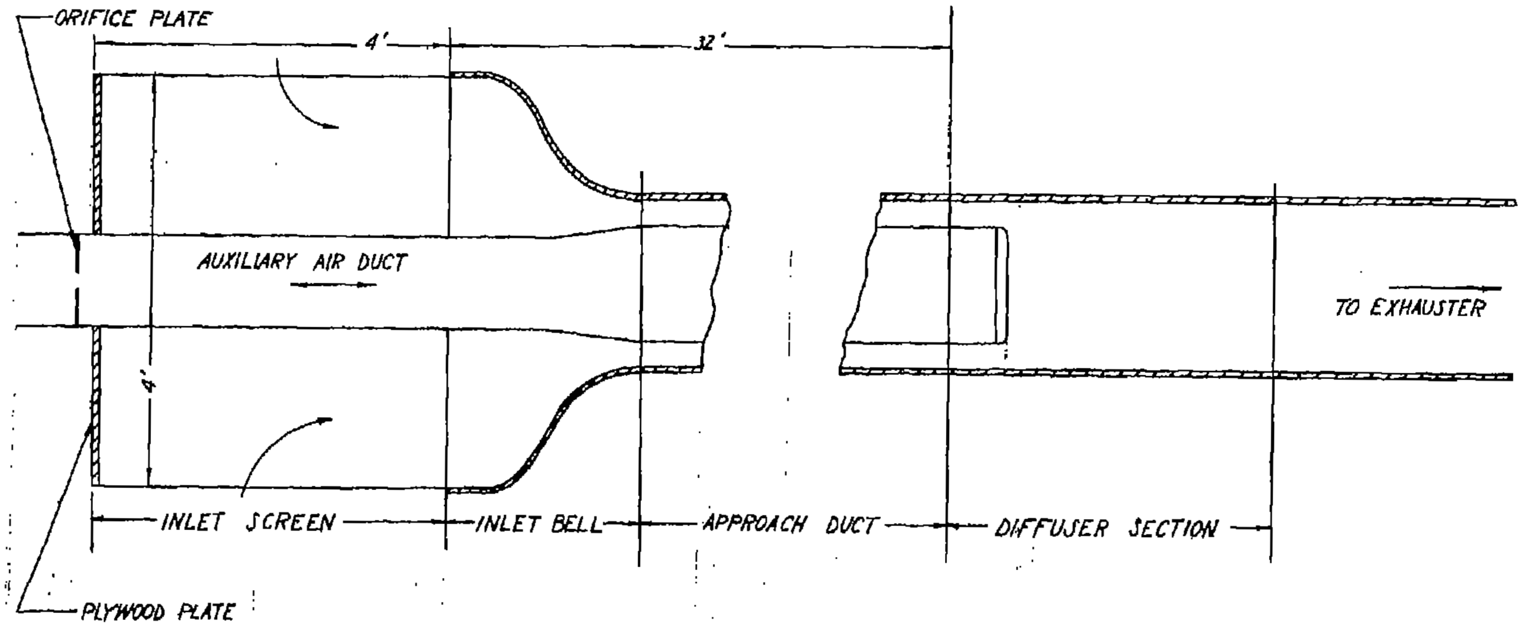


Figure 1.- Diagram of apparatus. Arrows denote direction of air flow.

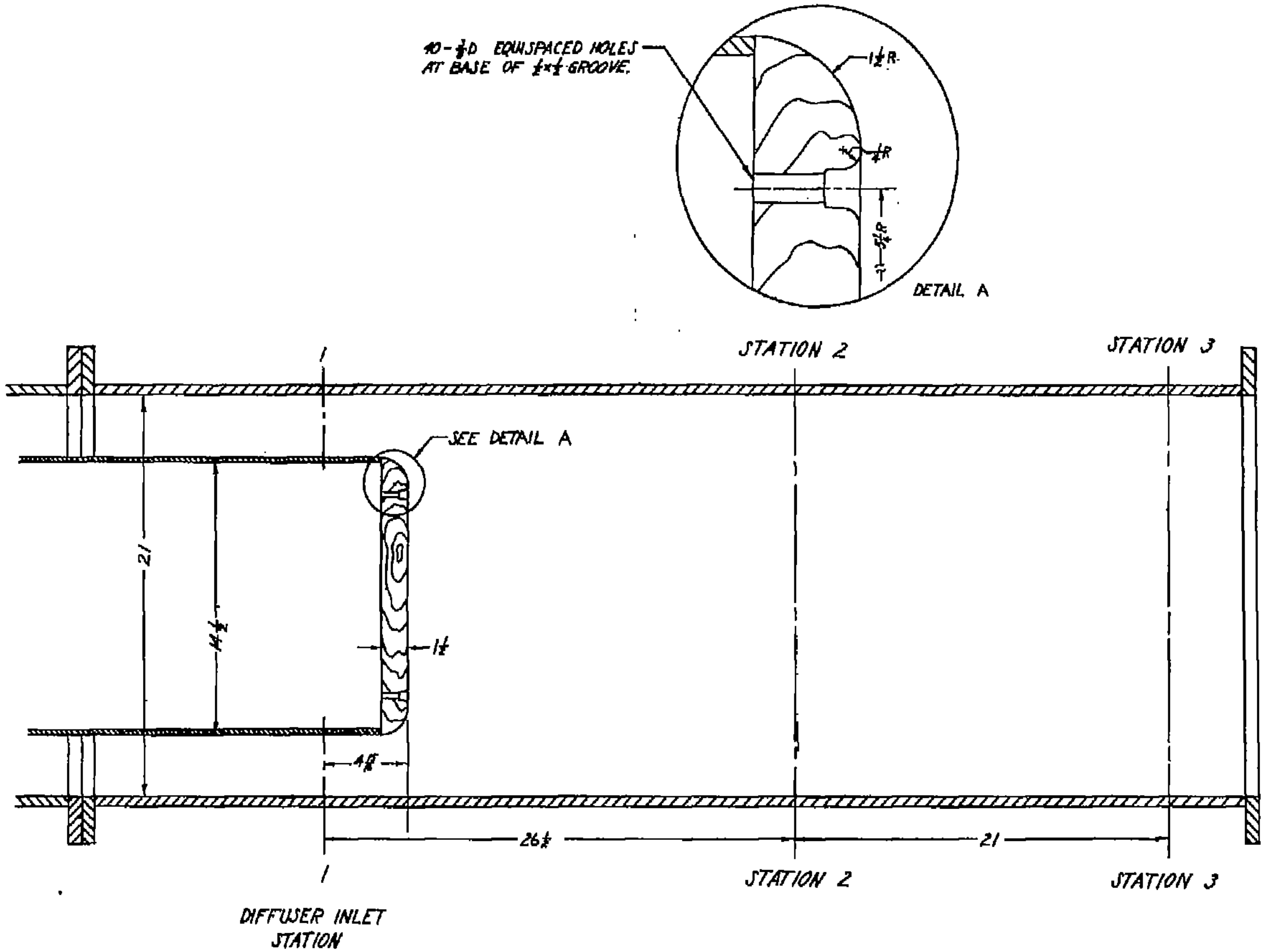


Figure 2.- General arrangement of modified dump and tailpipe. All dimensions are in inches.

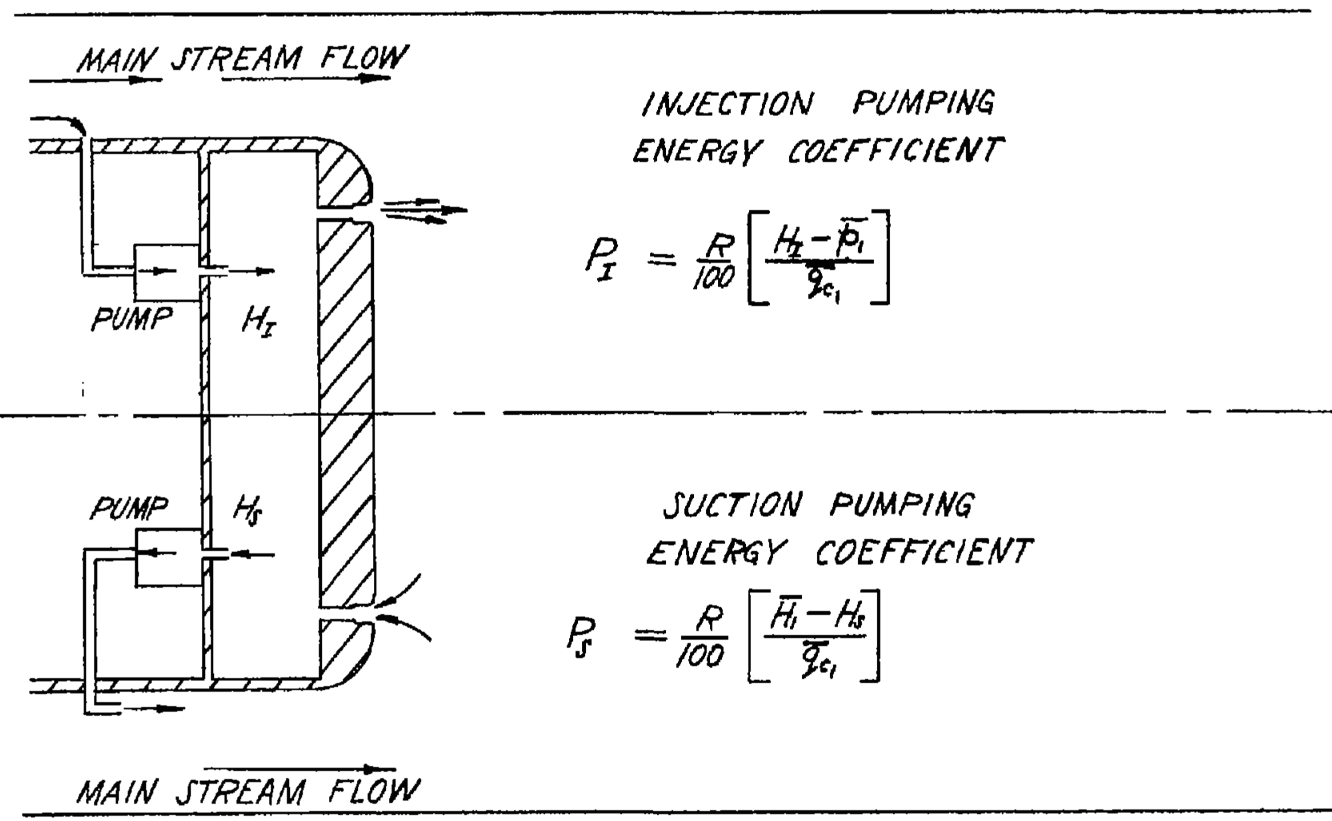


Figure 3.- Hypothetical auxiliary air system.

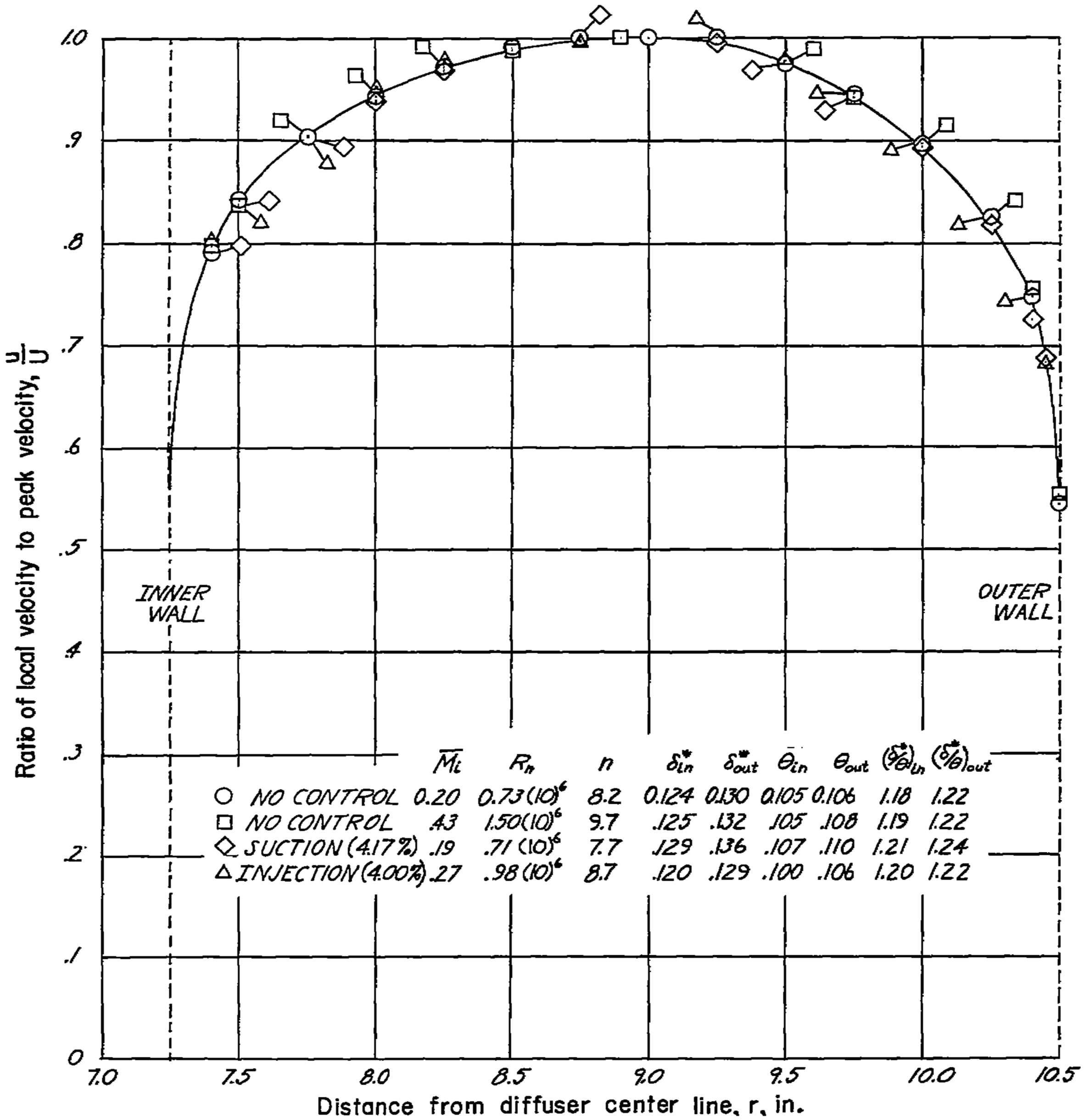


Figure 4.- Inlet velocity profiles at varying Mach number with and without auxiliary flow control.

[redacted]

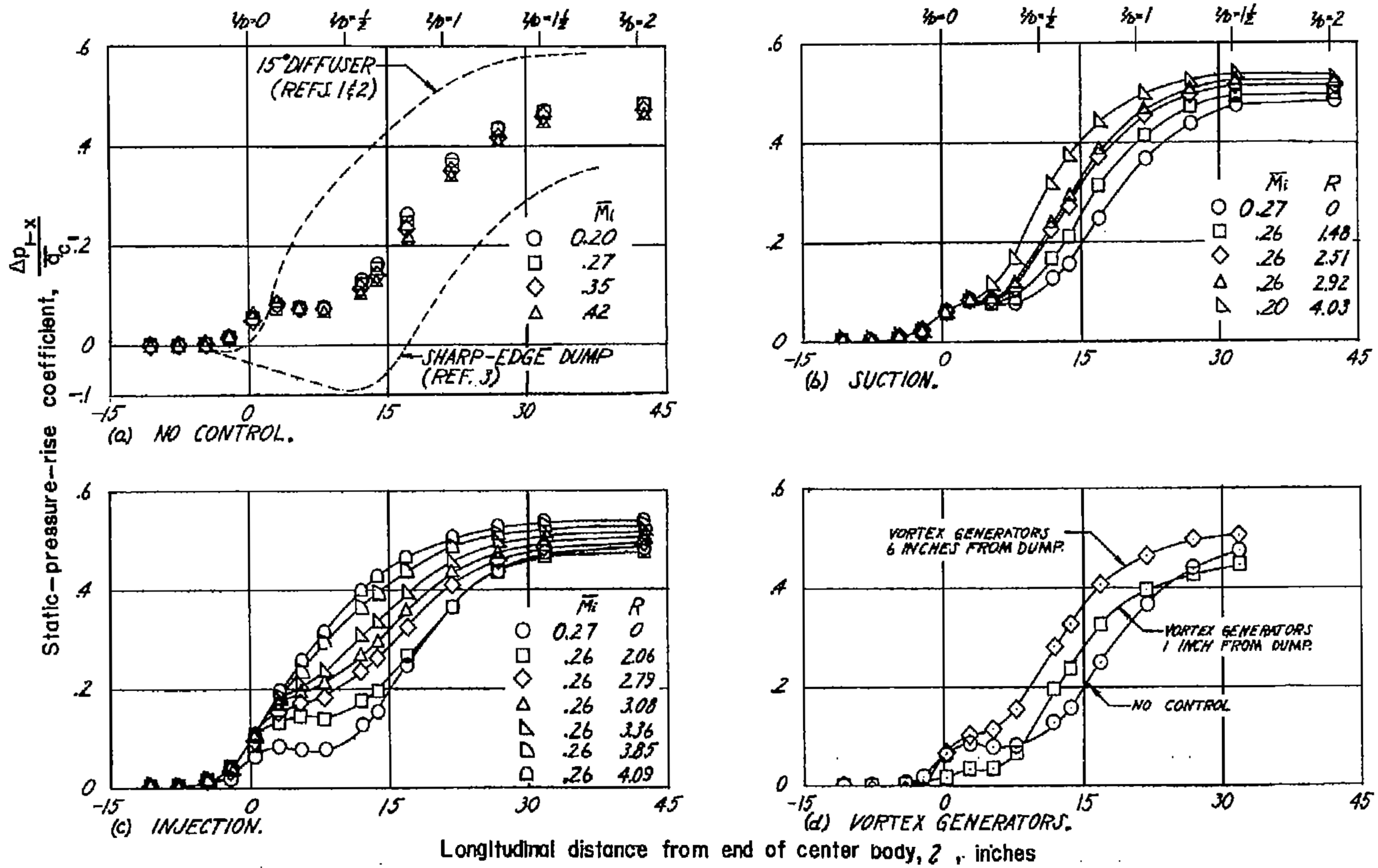
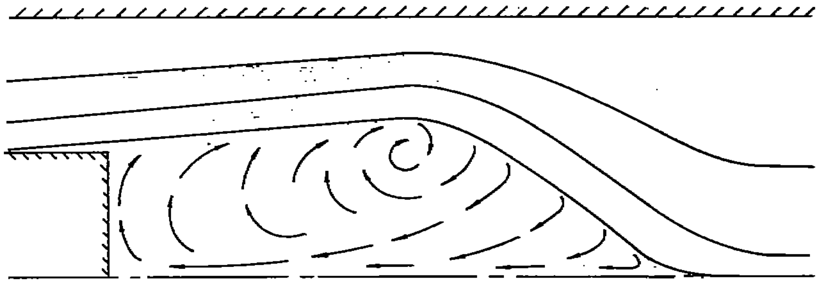
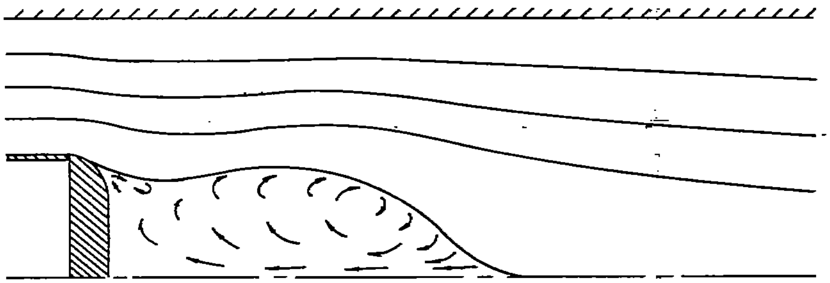


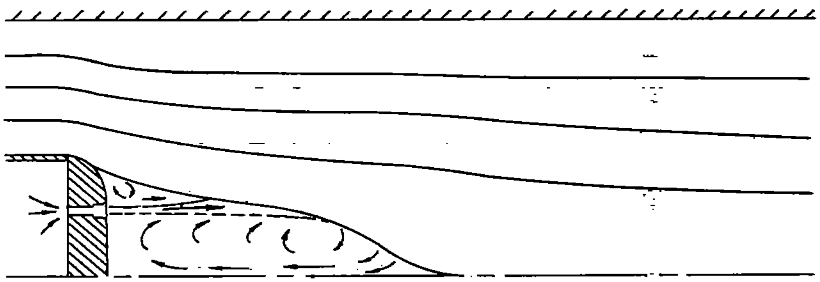
Figure 5.- Static-pressure-rise coefficient along diffuser outer wall.



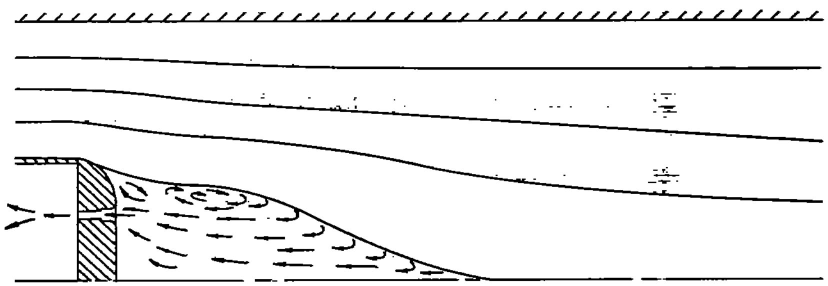
(a) Abrupt dump of reference 3.



(b) Modified dump with no control.



(c) Modified dump with injection.



(d) Modified dump with suction.

Figure 6.- Apparent flow patterns for an abrupt dump and a modified dump utilizing auxiliary flow.

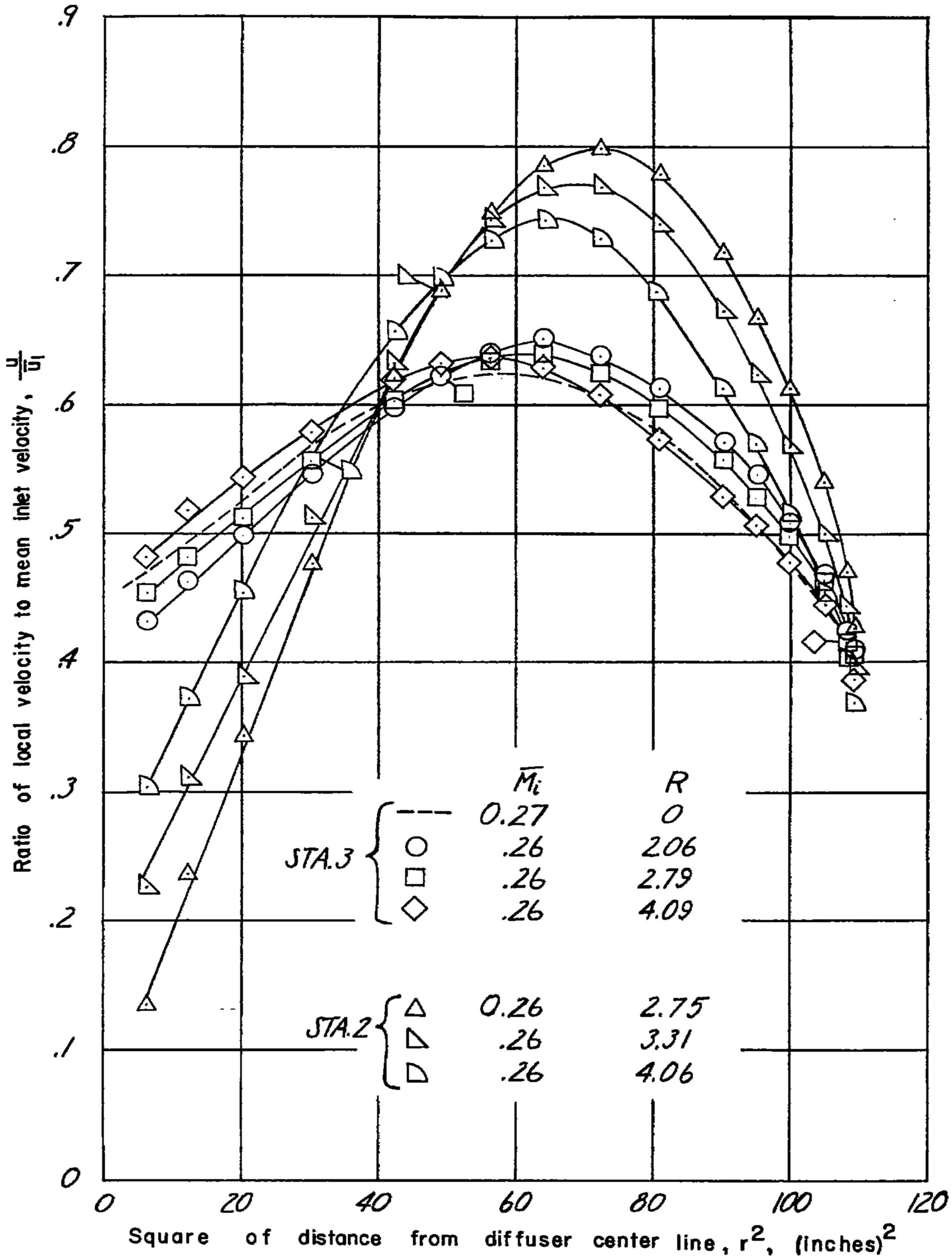


Figure 7.- Exit velocity profiles at stations 2 and 3 with injection of auxiliary flow.

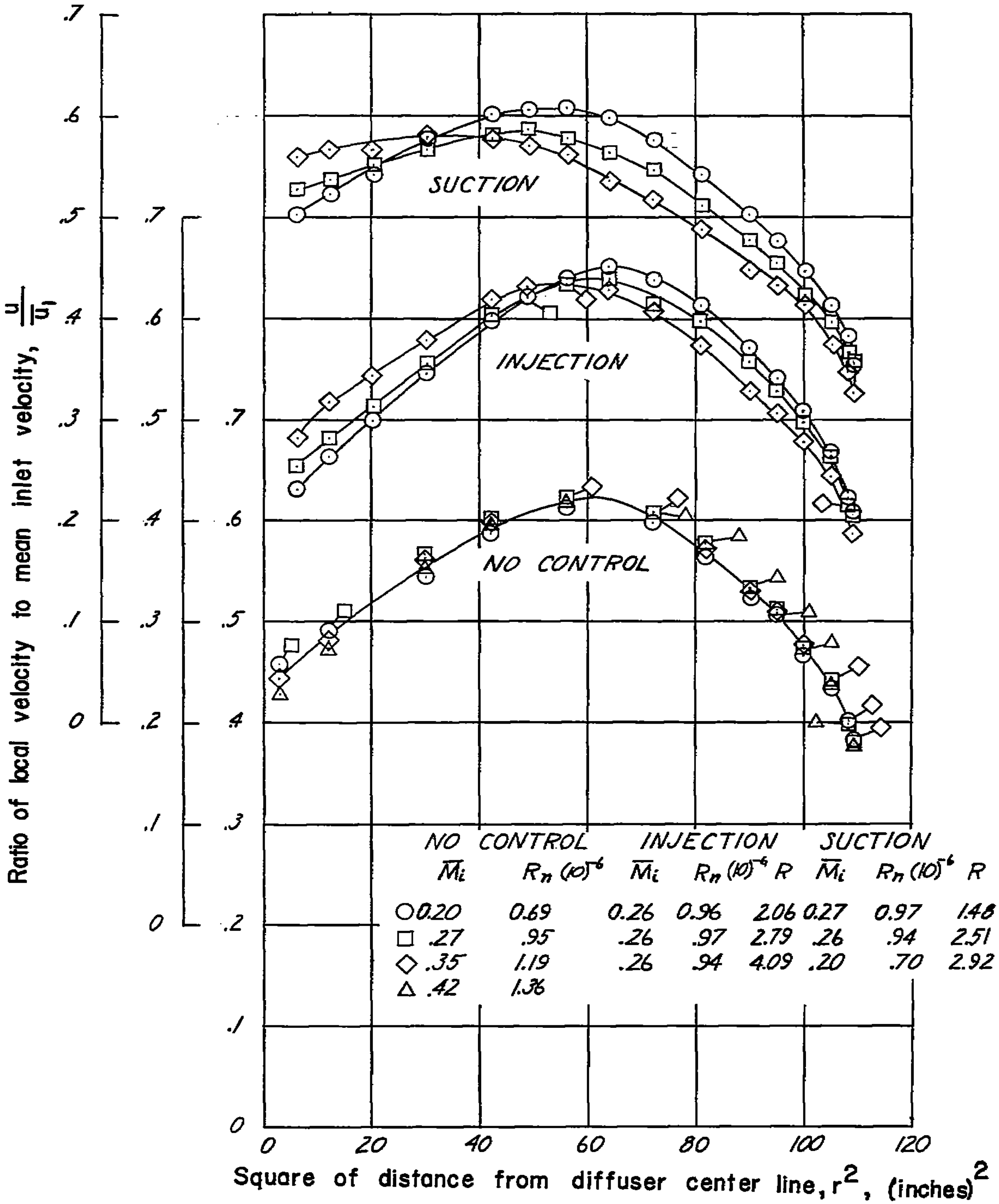


Figure 8.- Exit velocity profiles at station 3 for various auxiliary flow conditions.

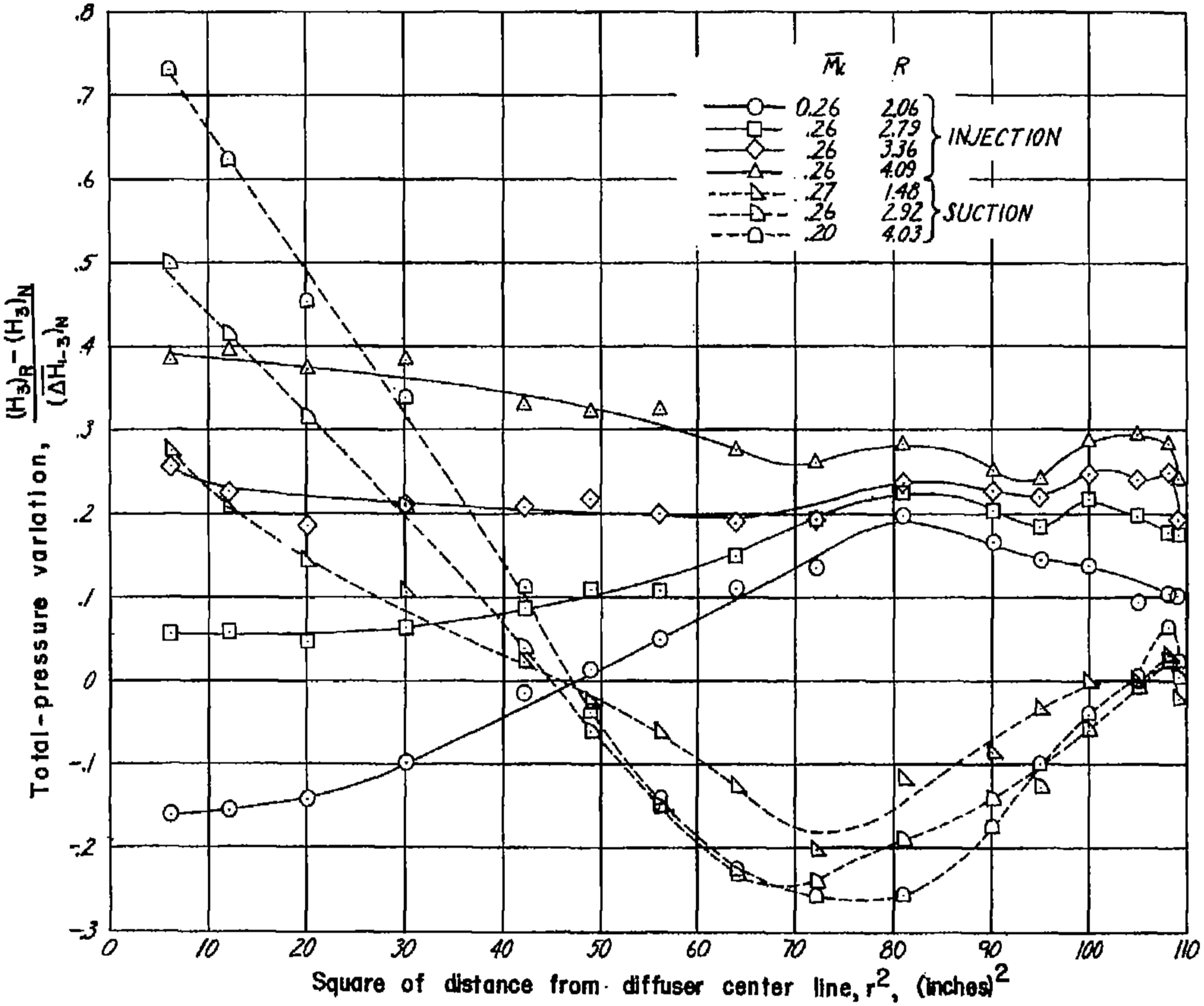


Figure 9.- Effect of auxiliary flow control on radial total-pressure distributions at station 3.

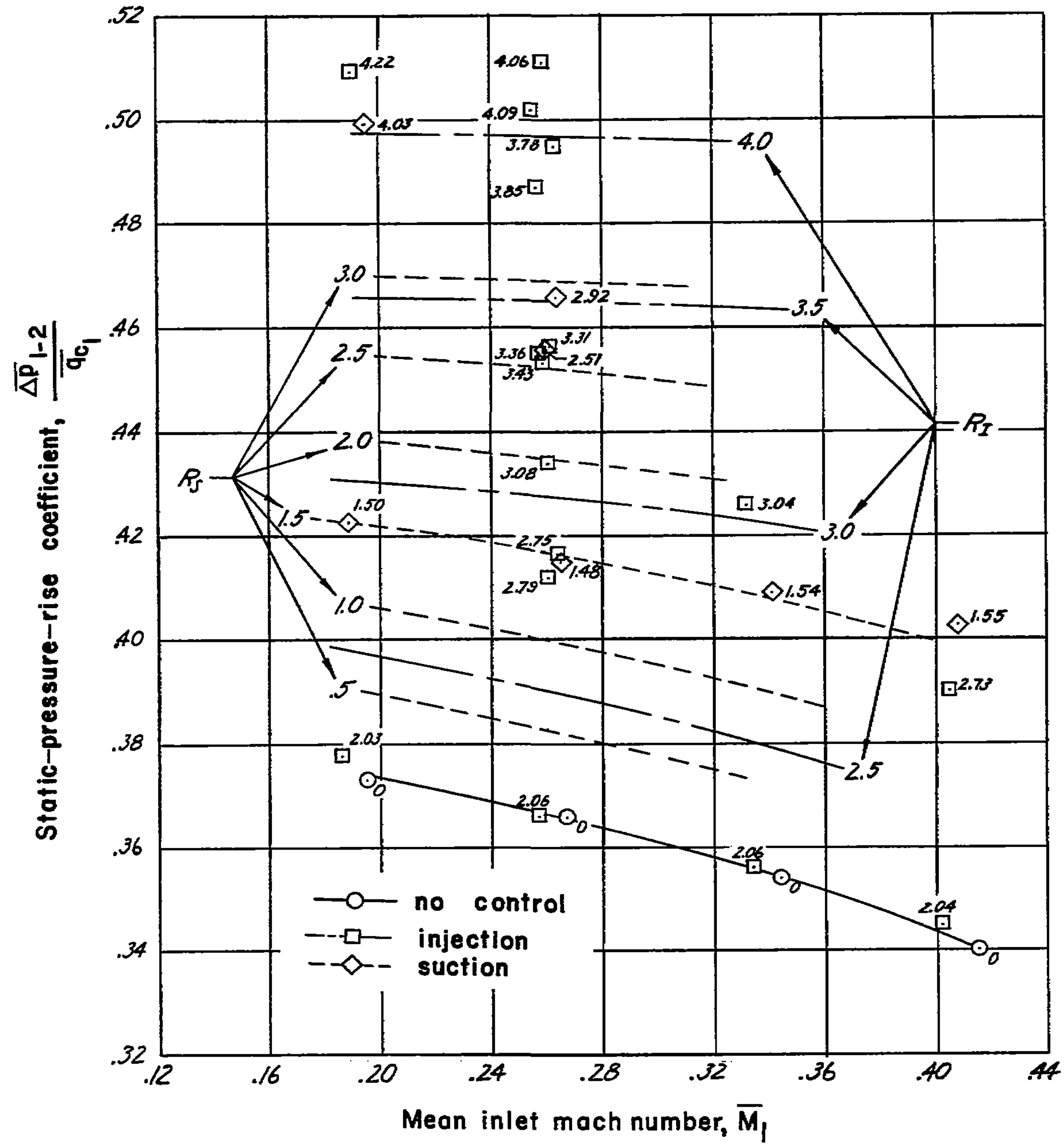


Figure 10.- Variation of static-pressure-rise coefficient at station 2 with mean inlet Mach number.

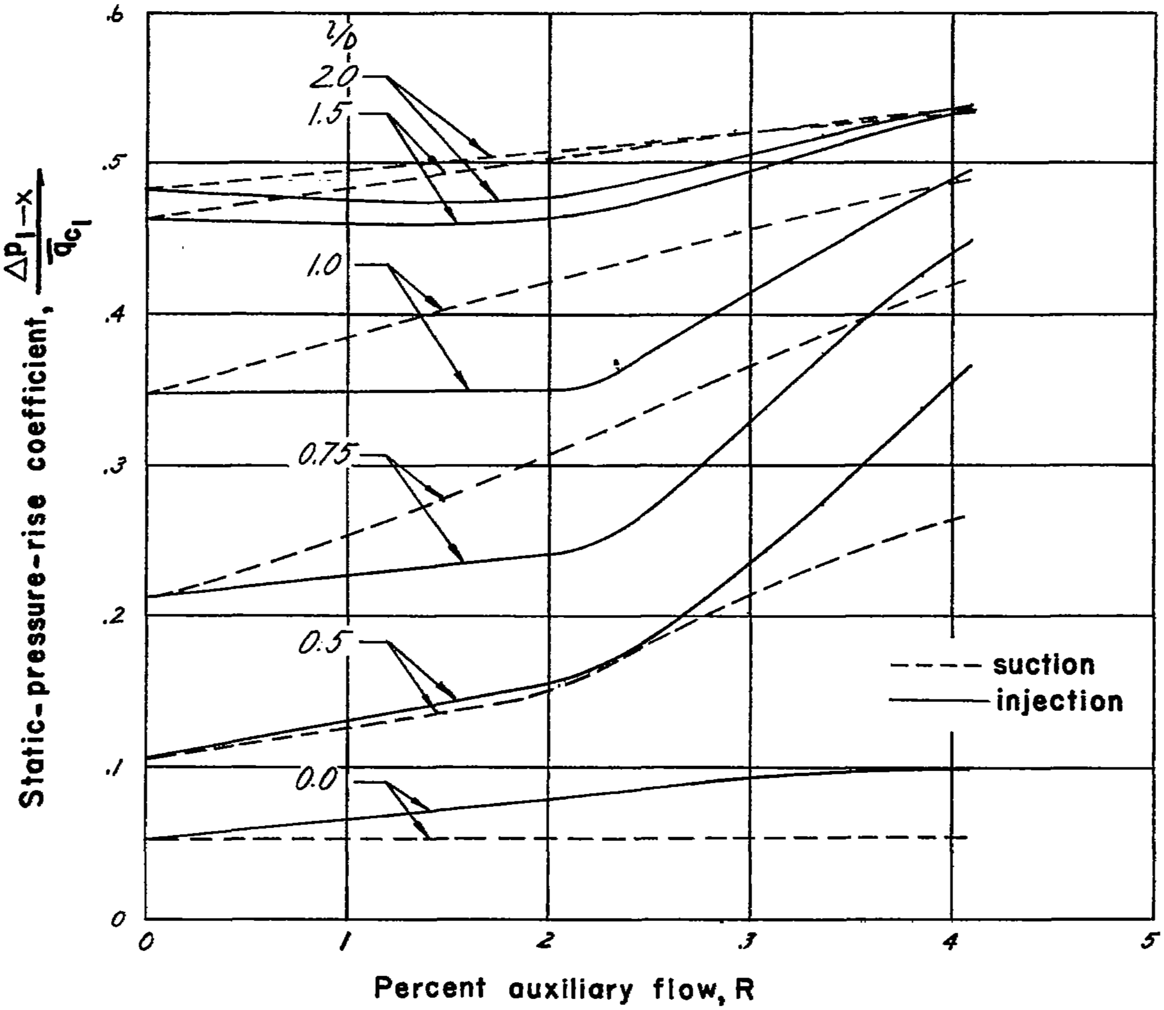


Figure 11.- Variation of static-pressure-rise coefficient with percent auxiliary flow at $\bar{M}_1 \approx 0.26$.

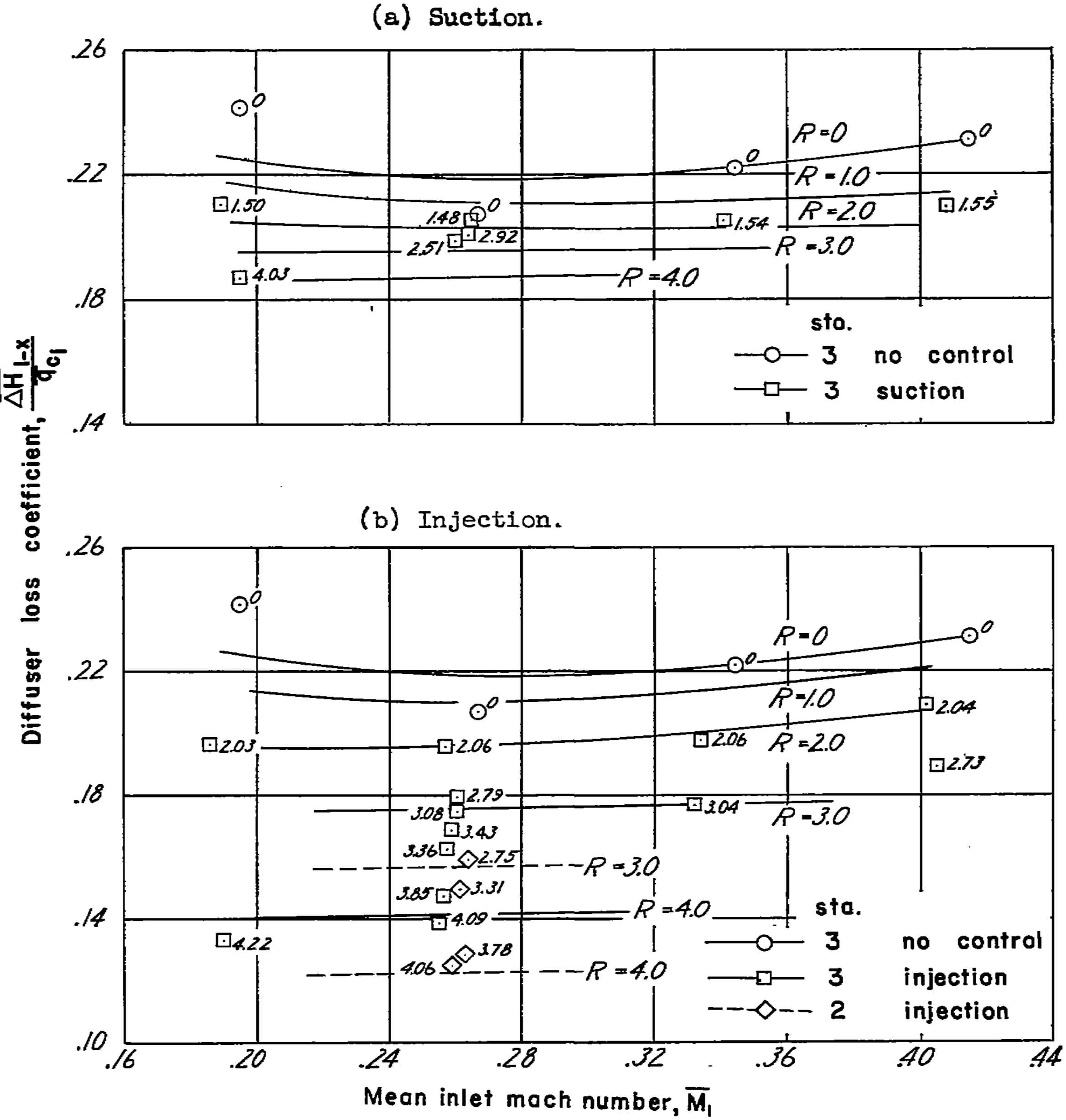


Figure 12.- Variation of loss coefficient with mean inlet Mach number.

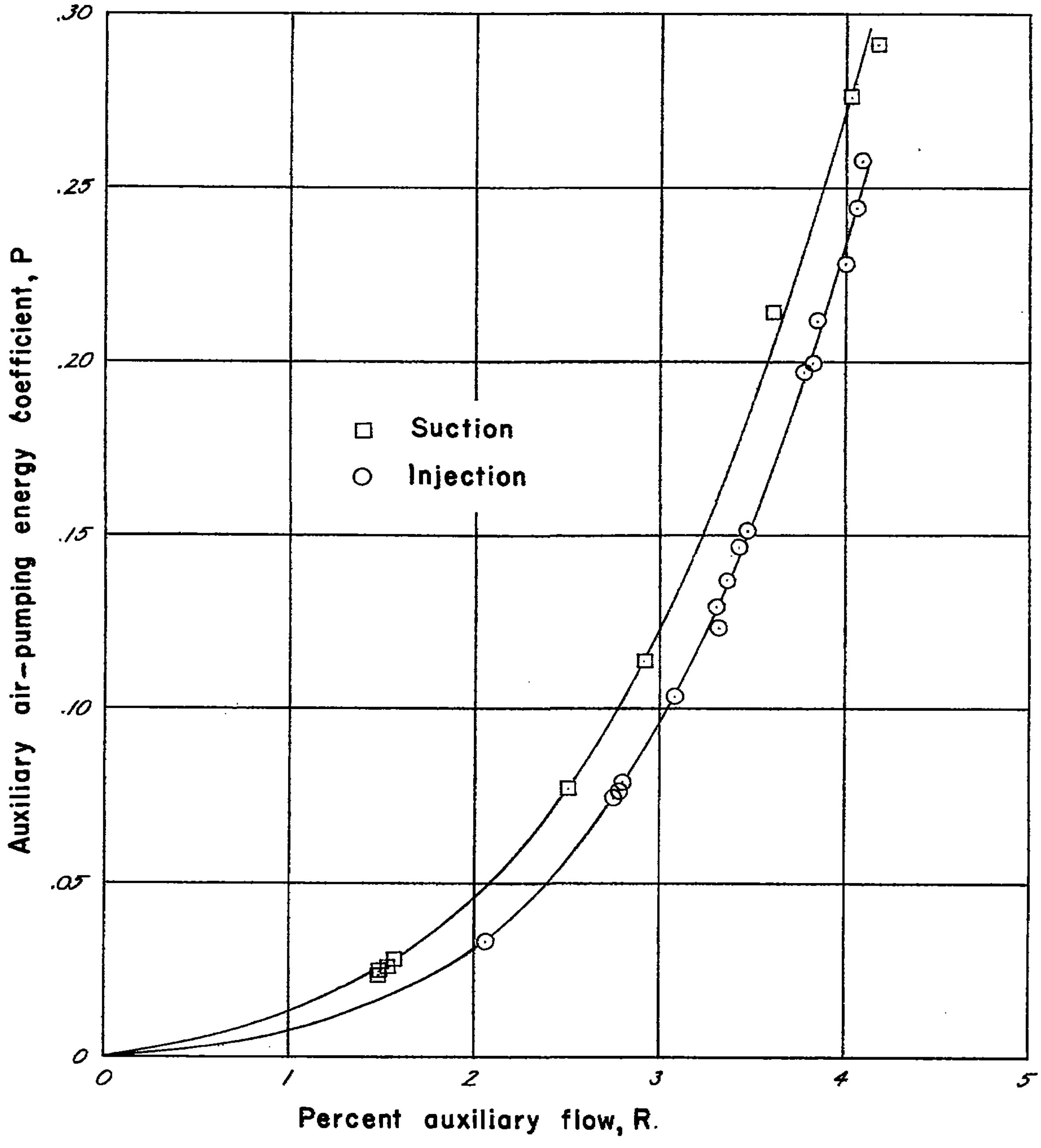


Figure 13.- Variation of auxiliary air-pumping energy coefficient with percent auxiliary flow.

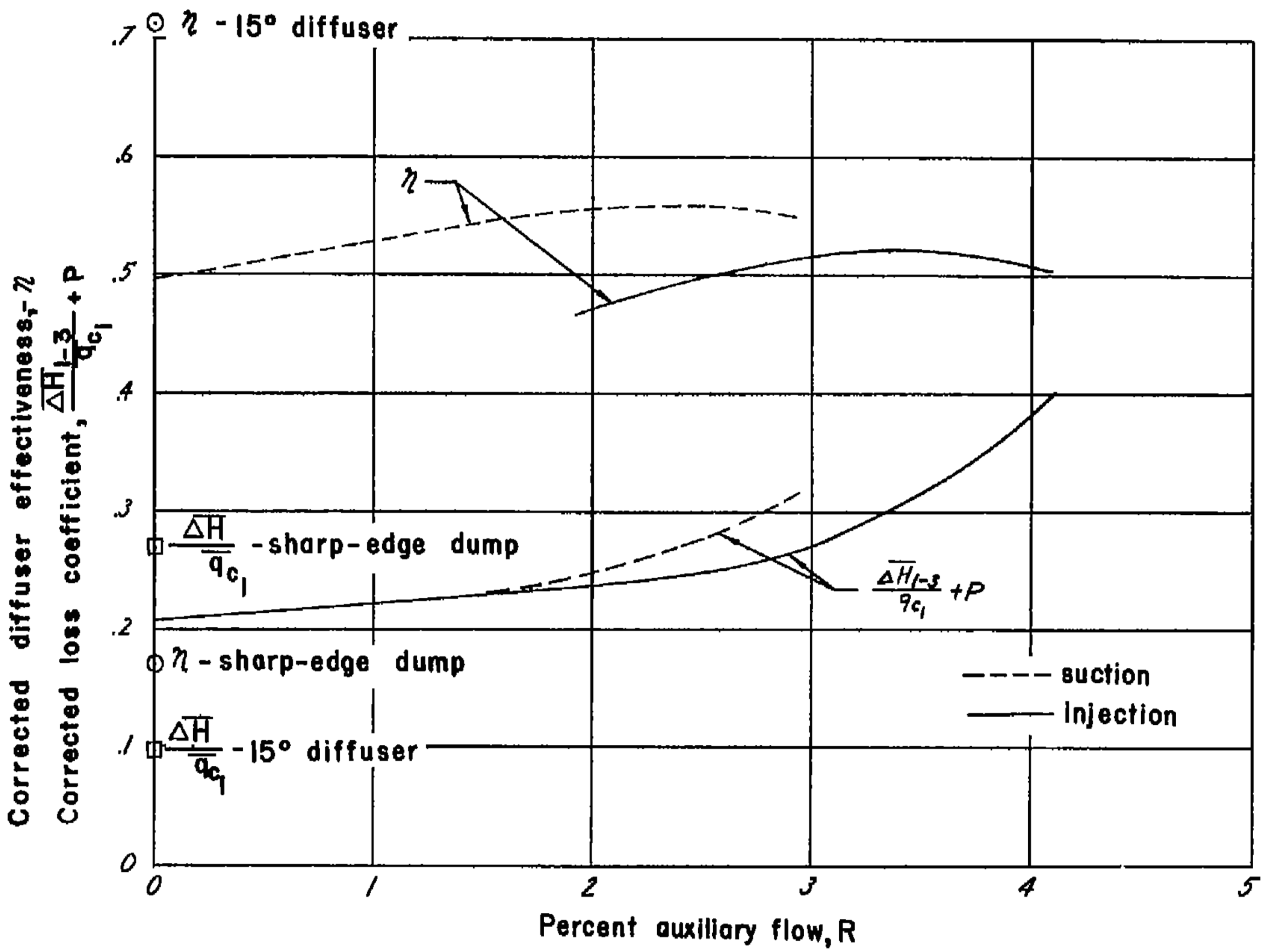


Figure 14.- Variation of corrected diffuser effectiveness at station 2 and corrected loss coefficient at station 3 with percent auxiliary flow.

[redacted]